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(54) Two-dimensional piezoelectric actuator.

(57) A micro displacer for accurate positioning in two directions in the same plane is disclosed. Two tabular piezoelectric elements (8a, 8b; 9a, 9b; 10a, 10b; 11a, 11b) with electrodes at the upper and lower surfaces thereof and a polarization axis along the thickness thereof are attached to the surfaces of each side of a strip of metal thin plate (7) in rectangular form thereby to form a laminated piezoelectric vibrator (8; 9; 10; 11). The central parts of a pair of opposed ones of the laminated piezoelectric vibrators (10, 11) are fixedly supported by fixing members (13a, 13b). The central parts of the other pair of the opposed laminated piezoelectric vibrators (8, 9) have a carriage (15) mounted thereon. The conduction of the upper and lower electrodes of the laminated piezoelectric vibrators is secured to provide independent voltage application terminals (16, 17, 18, 19), while the metal thin plate (7) provides a common voltage application terminal (20) for all the laminated piezoelectric vibrators (8, 9, 10, 11), whereby the laminated piezoelectric vibrators are rendered to function as piezoelectric vibrators cantilevered and supported at the ends thereby to permit bilateral displacement in the same plane.

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TWO-DIMENSIONAL PIEZOELECTRIC ACTUATOR

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

This invention relates to a two-dimensional piezoelectric actuator for accurate positioning in the desired direction on the same surface. This apparatus may find applications for positioning of a color solid-state image sensor for the video camera, a displacer for highresolution solid-state image sensor, a precision pattern positioning device and the like.

DESCRIPTION OF THE RELATED ART

In conventional methods of positioning by micro displacement in the order of microns or submicrons, mechanical means such as a stepping motor or a DC servo motor has been used for converting rotational motion into linear motion by a ball-type screw. The conventional mechanical apparatus has necessarily some errors due to mechanical connections and is therefore apt to be large in size in order to improve the precision thereof.

Then, a micro displacer using the reverse piezoelectric effect of a piezoelectric element capable of electrical control has been suggested. Such a displacer has a looper-type carriage mechanism as disclosed in the Japanese Patent Publication No. 12497/76. Fig. 10 is a diagram for explaining such a looper-type carriage mechanism having clamps 2, 3 operated by use of electro static or electromagnetic force at the ends of a cylindrical piezoelectric element 1. In Fig. 10(a), the clamps 2, 3 are clamped on a fixing table 4, and the clamp 3 is set free in Fig. 10(b). In Fig. 10(c), a voltage is applied to the piezoelectric element 1 to extend the same. In Fig. 10(d), the extended clamp 3 is clamped on the fixing table 4, and the clamp 2 is set free in Fig. 10(e). In Fig. 10(f), the applied voltage is removed, and in Fig. 10(g), the clamp 2 is clamped again. In this way, the same condition as in Fig. 10(a) is achieved, thus obtaining a displacement of Δl. A bilateral micro displacer is easily produced by mounting a similar carriage mechanism in two directions. The distortion caused by the reverse piezoelectric effect is so small that a highly accurate positioning is possible.

The Japanese Patent Laid-Open Publication No. 130677/83 and 196773/83, on the other hand, disclose a displacer for solid-state image sensor comprising a bending mode vibrator (bi-morph vibrator) with an end or both ends thereof fixed including a strip of piezoelectric elements attached on the upper and lower surfaces of a similarly-shaped thin metal plate, the piezoelectric element having a polarization axis along the thickness thereof, thus displacing the solid-state image sensor to increase the light-receiving area for a higher resolution. Fig. 11 shows a unilateral micro displacer using an example of such a bending mode vibrator. Bending mode vibrators 5, 5' with the ends thereof fixed are arranged in parallel to each other, and a carriage 6 having a solid-state image sensor or the like thereon is disposed at the central position of the bending mode vibrators 5, 5' where the amount of displacement is maximum.

A bilateral micro displacer is easily conceivable by mounting the above-mentioned looper-type micro displacer in two directions on the same surface. In view of the fact that one of the drive units is required to be clamped by electrostatic or electromagnetic force, however, an apparatus which is portable or used by being inclined is complicated in construction requiring separate means for fixing movable members while not in operation, resulting in a bulky apparatus. Also, the weight of movable objects while moving are concentrated at the part of the apparatus unclamped thereby to make the apparatus unstable. Further, the direction of motion is determined solely by the manner in which the apparatus is mounted, but the motion in the desired direction is impossible once the apparatus is mounted.

In a micro displacer using a bending mode vibrator, in spite of a large displacement allowable, the force generated is so weak that a heavy item cannot be moved. Also, under a heavy load, the resonant frequency of the vibrator is reduced, and the apparatus is rendered more liable to resonate to harmonic frequencies component of the drive frequency, thereby posing the problem of reduced durability. To obviate this problem by making micro displacement in the desired direction possible, a displacer (first displacement unit) with the bending mode vibrator described above may be used to displace another displacer (second displacement unit). Since the weight of the second displacement unit is exerted on the first displacement unit, however, the effect of the weight of the second displacement unit is required to be reduced by enlarging the bending mode vibrator of the first displacement unit, thereby leading to a bulky apparatus on the one hand and posing the problem of shorter durability on the other.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, there is provided a two-dimensional piezoelectric actuator comprising a rectangular metal thin plate, a plurality of independent laminated piezoelectric vibrators each including two tabular piezoelectric elements with a polarization axis along the thickness and electrodes at the upper and lower sides thereof, each of said piezoelectric vibrators being arranged vertically on each side of the rectangular metal thin plate, a plurality of fixing members for fixedly supporting a couple of opposed laminated piezoelectric vibrators by bonding or the like means at the central parts thereof, and a carriage at the central part of the apparatus between the opposed laminated piezoelectric vibrators, the upper and lower electrodes of the laminated piezoelectric vibrators making up independent voltage application terminals for conduction of the upper and lower sides of the laminated piezoelectric vibrators, the metal thin plate making up the other voltage application terminal common to all the laminated piezoelectric vibrators, the carriage being subjected to a micro displacement independently in two directions on the same surface by driving the piezoelectric vibrators independently.

According to another aspect of the present invention, there is provided a two-dimensional piezoelectric actuator in which upon application of a voltage to the voltage application terminals of the upper and lower electrodes of the laminated piezoelectric vibrators and the voltage application terminal of the metal thin plate, one of the tabular piezoelectric elements making up each laminated piezoelectric vibrator is extended while the other is compressed, thereby functioning as a bending mode vibrator causing flexion. The parts of the laminated piezoelectric vibrators on both sides of the fixing member for fixing the vibrators at the central part thereof provide bending mode vibrators of cantilever beam, so that the laminated piezoelectric vibrators having the carriage mounted thereon may be displaced along the normal line against the electrodes of the cantilevered beam mode vibrators. Each of the laminated piezoelectric vibrators having the carriage mounted at the central part thereof is a bending mode vibrator with the ends fixedly supported (a both ends-supported vibrator) and is capable of displacing the carriage along the normal line against the electrode surfaces thereof. As a result, a compact micro displacer with simplified construction is provided which is capable of independent micro displacements in two directions.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. lA, lB, and lC show bilateral micro displacer according to an embodiment of the present invention respectively, in which:

Fig. lA is a perspective view, lB an exploded perspective view, and lC an exploded perspective view of a laminated piezoelectric vibrator.

Fig. 2 is an exploded perspective view of a bilateral micro displacer in packaged form according to the present invention.

Figs. 3A and 3B, Fig. 4, Fig. 5, Fig. 6 and Fig. 7 show other embodiments of the present invention, in which Fig. 3A is a perspective view, Fig. 3B an exploded perspective view, Fig. 4, Fig. 5 and Fig. 6 exploded perspective views of a laminated piezoelectric vibrator, and Fig. 7 an exploded perspective view of a micro displacer.

Fig. 8 is an exploded perspective view of a laminated piezoelectric vibrator.

Fig. 9A is a perspective view of a micro displacer for a solid-state image sensor, and Fig. 9B an exploded perspective view.

Fig. l0 and Fig. ll are front view and perspective view of a conventional micro displacer.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be explained in detail below with reference to the accompanying drawings.

Figs. lA, lB and lC show an embodiment of the present invention, in which Fig. lA is a perspective view, lB an exploded perspective view, and lC an exploded perspective view of a laminated piezoelectric vibrator. A rectangular metal thin plate 7 which is arranged in a rectangular form has vertically attached on the respective sides thereof tabular piezoelectric elements 8a, 8b; 9a, 9b; l0a, l0b; lla, llb with a polarization axis along the thickness and upper and lower electrodes, which tabular piezoelectric elements are so attached that the polarization axes thereof are arranged in the same direction, thereby constituting laminated piezoelectric vibrators 8, 9, l0, ll independent of each other. The central parts of the laminated piezoelectric vibrators l0, ll are fixedly supported by bonding or screw with recessed fixing members l3a, l3b mountable to the base board l2, while the central parts of the piezoelectric vibrators 8, 9 have mounted thereon a carriage l5 for carrying a movable member such as a solid-state image sensor l4. In order to assure conduction between the upper and lower electrodes of the laminated piezoelectric vibrators 8, 9, l0, ll, voltage application terminals l6, l7, l8, l9 are provided, and the metal thin plate 7 is

used as a common voltage application terminal 20 for the voltage application terminals 16, 17, 18, 19. Upon application of a voltage to the voltage application terminals 20 and 16, 17, the laminated piezoelectric vibrators 8, 9 function as a both ends-supported vibrator and are displaced along the normal line against the electrode surfaces. The amount of this displacement is proportional to the applied electric field and piezoelectric constant d31. Assume that the laminated piezoelectric elements 8a, 8b, 9a, 9b have the same thickness, and the polarization axes of the opposed laminated piezoelectric vibrators 8, 9 are arranged in the same direction. Upon application of a voltage of the same phase, the laminated piezoelectric vibrators 8, 9 are displaced in the same amount in the same direction, so that it is possible to displace the carriage mounted at the central parts thereof along the direction of displacement of the laminated piezoelectric vibrators 8, 9, that is, along the normal line against the electrode surfaces. The laminated piezoelectric vibrators 10, 11, with the central parts thereof fixedly supported by the fixing members 13a, 13b, on the other hand, function as a cantilever beam mode vibrator. When a voltage is applied to the terminals 20, 18, 19 in such a manner as to cause a displacement of the same amount in the same direction, the laminated piezoelectric vibrators 8, 9 are displaced in the same direction, that is, along the normal line against the electrode surfaces of the piezoelectric vibrators 10, 11, thus displacing the carriage 15 in the same direction. In view of the fact that the laminated piezoelec tric vibrators 8, 9 and 10, 11 can be driven independently of each other, the carriage 15 is displaceable in two directions on the same surface. Also, since the laminated piezoelectric vibrators 8, 9, 10, 11 are constructed in the same plane, a compact micro displacer capable of independent bilateral displacement simple in construction is provided. If conduction is assured with a grounding terminal between the voltage application terminals 16, 17, 18, 19 of the upper and lower electrodes of the laminated piezoelectric vibrators and the fixing members, on the other hand, the resulting fact that the metal thin plate 7 providing a common voltage application terminal 20 is sandwiched between grounding electrodes reduces intrusion of noises while at the same time preventing shorting by external contact.

The advantage of a reduced size leads to the great feature that the displacer is packaged with semiconductors in such applications as micro displacement of the semiconductors including the solid-state image sensor. Fig. 2 shows an example of such a package. A solid-state image sensor 14 is fixed on a carriage 15 of a bilateral micro displacer by conductive adhesive or the like, and the bilateral micro displacer is fixedly mounted within a case 21 of ceramics or the like. The assembly is sealed in a case 21 with glass transparent to the light radiated on the light-receiving surface of the solid-state image sensor 14. The electric wiring to the piezoelectric elements required for bilateral displacement and the solid-state image sensor are led out through an electrode 20 printed on the case 21.

Now, another embodiment of the present invention will be described with reference to Figs. 3A and 3B. Fig. 3A is a perspective view and Fig. 3B an exploded perspective view. The upper and lower electrodes 10a', 10b'; 11a', 11b' of the piezoelectric vibrators 10, 11 fixedly supported by fixing members at the central parts thereof are isolated at the central parts thereof as shown by hatching in Fig. 3B thereby to assure conduction of the upper and lower electrodes, thus making up voltage application terminals 18a, 18b, 19a, 19b. By applying a voltage between these electrodes and a common voltage application terminal 20, the cantilever beam mode vibrators on the sides of the fixed parts are driven independently. Assume, for instance, that the laminated piezoelectric elements have the same thickness, and the opposed laminated piezoelectric vibrators 10, 11 have the same direction of polarization axis. When a voltage of the same phase is applied to the voltage application terminals 20 and 18a, 19b, the laminated piezoelectric vibrator 8 is displaced, while by applying a voltage of the same phase to the voltage application terminals 20 and 18b, 19b in a similar manner, the laminated piezoelectric vibrator 9 is displaceable. Specifically, the laminated piezoelectric vibrators 8 and 9 are displaced independently of each other. By applying different voltages to the voltage application terminals 18a, 19a and 18b, 19b, therefore, the amount of displacement of the laminated piezoelectric vibrators 8, 9 are differentiated thereby to incline the carriage 15 in the horizontal plane. This leads to the feature that any inclination of the solidstate image sensor mounted on the base within the horizontal plane is correctable and the angle adjustable in such applications as precision micro positioning in mask matching of integrated circuits or the like.

Fig. 4 is an exploded perspective view of laminated piezoelectric vibrators according to still another embodiment of the present invention. Piezoelectric vibrators with the central parts thereof fixedly supported by fixing members are constructed of tabular piezoelectric elements 21a, 21b; 22a, 22b; 23a, 23b; 24a, 24b applied vertically on the surfaces of the metal thin plate 7 in such a manner as to be separated at the central parts thereof. In this construction, the piezoelectric vibrators on the

sides on the fixing members are drivable independently, thereby resulting in the great advantage that an inclination can be corrected or micro positioning is made possible as described above.

Fig. 5 is an exploded perspective view of a laminated piezoelectric vibrators according to a further embodiment of the present invention. A rectangular metal thin plate 7 is formed by bending a metal sheet, and is configured in such a manner that the ends of the metal thin plate 7 are located at the central parts of the piezoelectric elements 10a, 10b to be laminated. In view of the fact that the ends of the metal thin plate are positioned at the parts fixed by the fixing members, the amount of displacement as a piezoelectric vibrator is not affected, and also the fact that the rectangular thin metal plate can be obtained from a sheet of metal simplifies the construction easy to fabricate.

Fig. 6 is an exploded perspective view of a laminated piezoelectric vibrator according to a still further embodiment of the present invention. Rectangular metal thin plates 7a, 7b bent in channel shape are opposed to each other thereby to make up a rectangular metal thin plate formed in rectangle with the ends of the metal thin plates 7a, 7b at the central parts of the piezoelectric elements 10a, 10b; 11a, 11b to be laminated. The metal thin plates 7a, 7b are fabricated by being bent only in one direction, thereby leading to a high mass production efficiency.

Fig. 7 is an exploded view of a micro displacer according to another embodiment of the present invention. Micro displacement units 25a, 25b with tabular piezoelectric elements attached vertically on the surfaces of rectangular metal thin plates 7a, 7b bent in channel shape and are arranged with the ends thereof opposed to each other. The ends of the micro displacement units 25a, 25b are fixedly supported by fixing members 13a, 13b. Since this apparatus is constructed of fully independent micro displacement units, the great advantage results that the variations in the characteristics of the piezoelectric cantilever beam mode vibrators are offset by adjusting the length of the fixed parts of the piezoelectric vibrators at the time of mounting thereof by the fixing members.

Fig. 8 is an exploded perspective view of a laminated piezoelectric vibrator according to a still another embodiment of the present invention. In view of the fact that a piezoelectric cantilever beam mode vibrator is coupled with a laminated both ends-supported vibrator thereof by a metal thin plate, they are affected by each other. Neverthless, the modulus of flexural rigidity of the metal thin plates on the sides of the laminated piezoelectric both ends-supported vibrator thereof supported is increased by forming U-shaped recesses 26a, 26b, 26c, 26d as shown in Fig. 7 or narrow parts 26a', 26b', 26c', 26d'. In this way, the reliability is improved with a reduced mutual effect. Further, if apertures 27 are formed in the metal thin plate, piezoelectric elements are bonded to each other at these parts thereby to improve the bonding strength between the metal and piezoelectric elements.

Figs. 9A and 9B are diagrams showing a micro displacer for a solid-state image sensor according to another embodiment of the present invention. Fig. 9A is a perspective view of the apparatus, and Fig. 9B an exploded perspective view thereof. A solid-state image sensor device 27 is mounted on a carriage 15. Signals of the solid-state image sensor device 27 and signals applied to voltage application terminals 16, 17, 18, 19 of laminated piezoelectric vibrators 8, 9, 10, 11 are connected to a flexible base board 29 for connection to a printed board 28 mounted on the bottom of the base board 12. This construction provides an apparatus capable of accurate adjustment of mounting positions and color matching for a given solid-state image sensor device.

It will thus be understood from the foregoing description that according to the present invention, there is provided a compact micro displacer simple in construction which is capable of independent displacement in two directions, comprising laminated piezoelectric vibrators of cantilever type and laminated piezoelectric vibrators with the ends thereof supported, both vibrators being configured in the same plane.

Claims

1. A two-dimensional piezoelectric actuator comprising a plurality of piezoelectric vibrators (8, 9, 10, 11) each including two tabular piezoelectric elements (8a, 8b; 9a, 9b; 10a, 10b; 11a, 11b) laminated to each other on the sides of a rectangular metal thin plate (7), said tabular piezoelectric elements (8a, 8b; 9a, 9b; 10a, 10b; 11a, 11b) having a polarization axis along the thickness thereof and electrodes (16, 17, 18, 19) at the upper and lower surfaces thereof a plurality of fixing members (13a, 13b) for fixedly supporting a pair of opposed laminated piezoelectric vibrators (10, 11) at the central parts thereof, and a carriage (15) mounted on the other pair of laminated piezoelectric vibrators (8, 9) opposed to each other.

2. A two-dimensional piezoelectric actuator according to Claim 1, wherein the conduction of the upper and lower electrodes (16, 17, 18, 19) of said laminated piezoelectric vibrators is secured to provide independent voltage application terminals (16,

(7, 18, 19), and said metal thin plate (7) provides a common voltage application terminal (20) for all the laminated piezoelectric vibrators.

3. A two-dimensional piezoelectric actuator wherein the upper and lower electrodes of laminated piezoelectric vibrators (10, 11) fixedly supported by fixing members (13a, 13b) are isolated at the central parts thereof thereby to secure conduction of the upper and lower electrodes, thereby providing independent voltage application terminals.

4. A two-dimensional piezoelectric actuator according to anyone of Claims 1 to 3, wherein the tabular piezoelectric elements (10a, 10b; 11a, 11b) of the pair of the piezoelectric vabrators (10, 11) fixedly supported at the central parts thereof by fixing members (13a, 13b) are isolated at the fixed parts thereof.

5. A two-dimensional piezoelectric actuator according to anyone of Claims 1 to 4, wherein a strip of metal thin plate is bent into a rectangular form of metal thin plate (7), the ends of said metal thin plate (7) coinciding with the fixed central parts of the laminated piezoelectric vibrators (10, 11) fixedly supported by the fixing members (13a, 13b).

6. A two-dimensional piezoelectric actuator according to anyone of Claims 1 to 4, wherein two channel-shaped strips of metal thin plates (7a, 7b) are formed into a rectangular form of metal thin plates, the ends of said two metal thin plates (7a, 7b) coinciding with the central fixed parts of the laminated piezoelectric vibrators (8, 9) fixedly supported by fixing members (13a, 13b).

7. A two-dimensional piezoelectric actuator according to anyone of Claims 1 to 4, comprising two micro displacement units (25a, 25b) each including tabular piezoelectric elements attached to the upper and lower surfaces of a strip of metal thin plate bent into a channel shape, said micro displacement units (25a, 25b) being arranged with the ends thereof opposed to each other, said ends being fixedly supported by fixing members (13a, 13b).

8. A two-dimensional piezoelectric actuator according to anyone of Claims 1 to 7, wherein a plurality of apertures (27) are formed in a strip of metal thin plate formed into rectangle.

9. A two-dimensional piezoelectric actuator according to anyone of Claims 1 to 8, wherein the modulus of flexural rigidity of the metal thin plate (7) at the ends of the laminated piezoelectric vibrators (8, 9) having a carriage (15) mounted thereon is increased.

10. A two-dimensional piezoelectric actuator according to anyone of Claims 1 to 9, wherein the carriage (15) has mounted thereon a solid-state image sensor (14).

11. A two-dimensional piezoelectric actuator according to Claim 10, comprising a flexible base board (12) wherein signals of the solid-state image sensor (14) mounted on the carriage (15) and voltage application signals of the laminated piezoelectric vibrators (8, 9, 10, 11) are produced externally.

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FIG. 1A

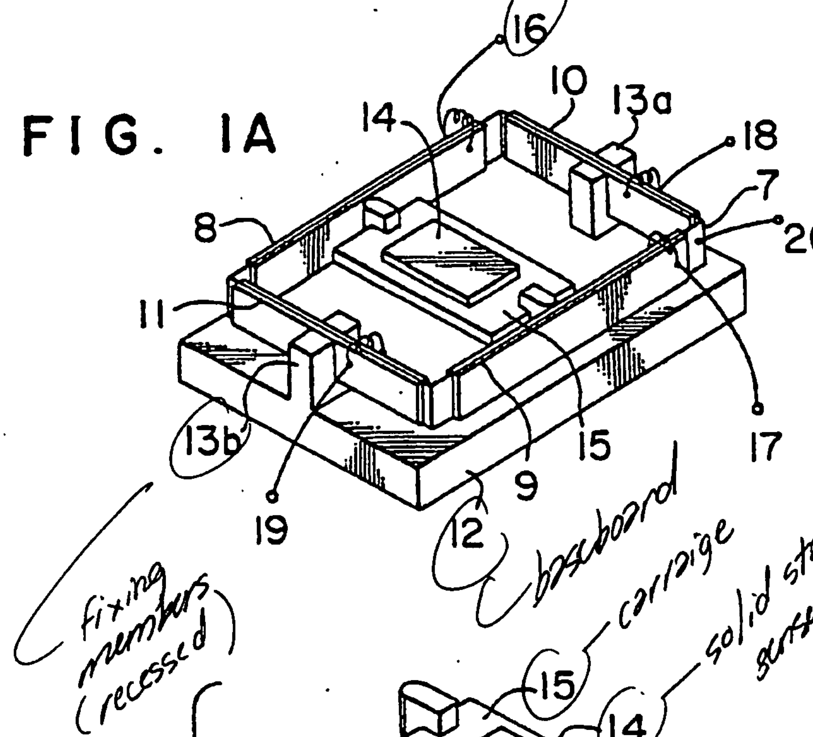


FIG. 1B

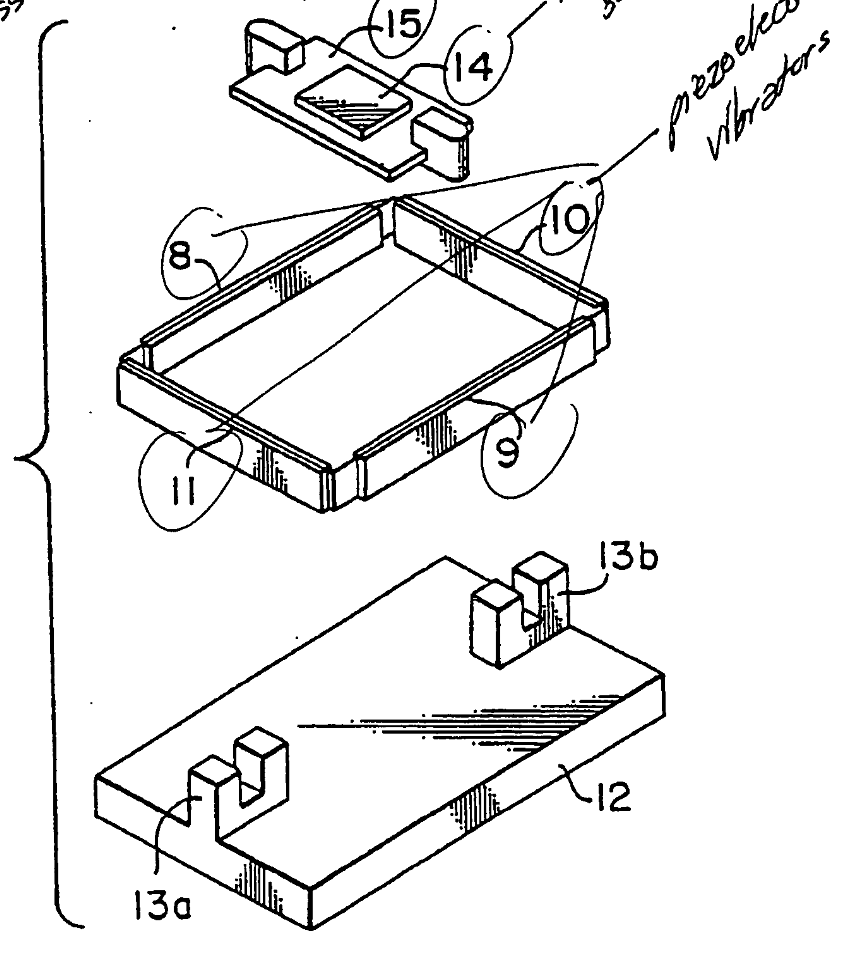


FIG. 1C

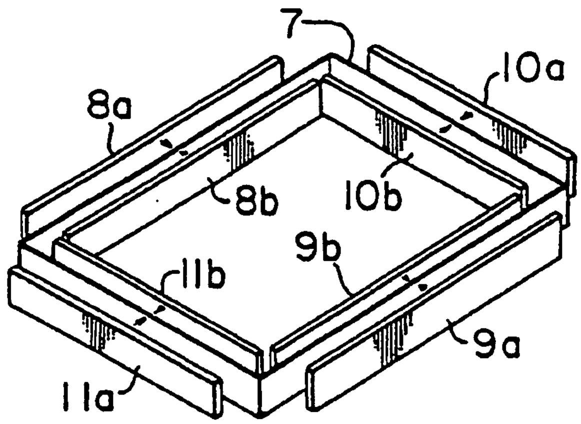
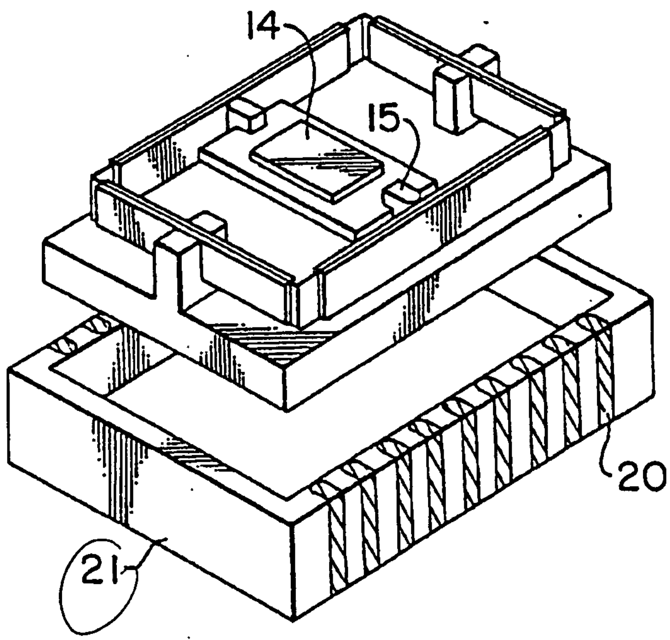


FIG. 2



Case

FIG. 3A

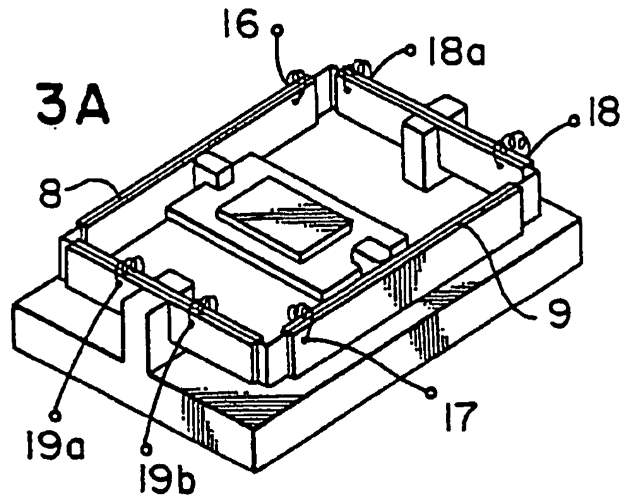


FIG. 3B

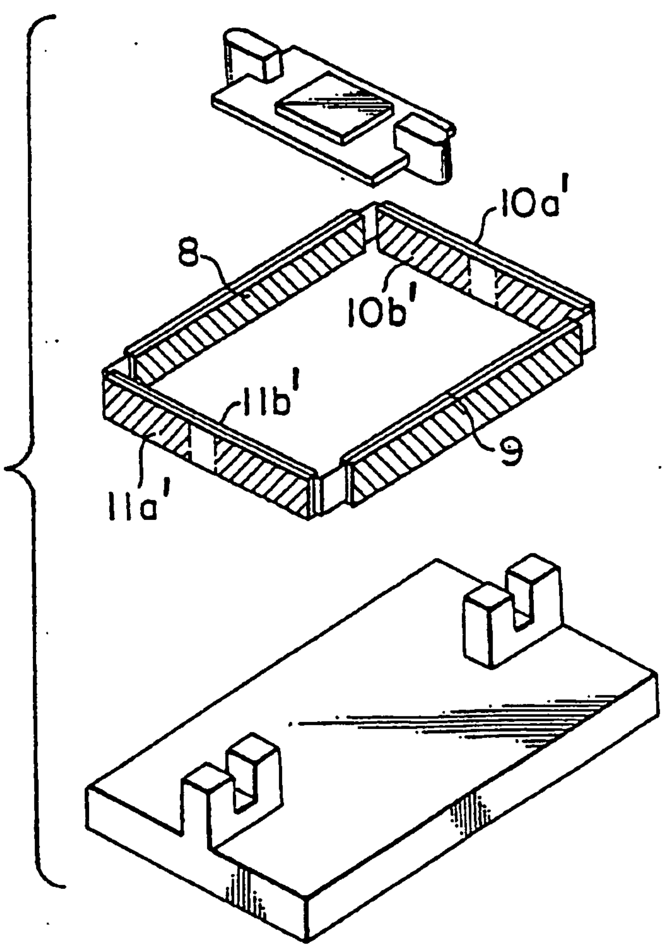


FIG. 4

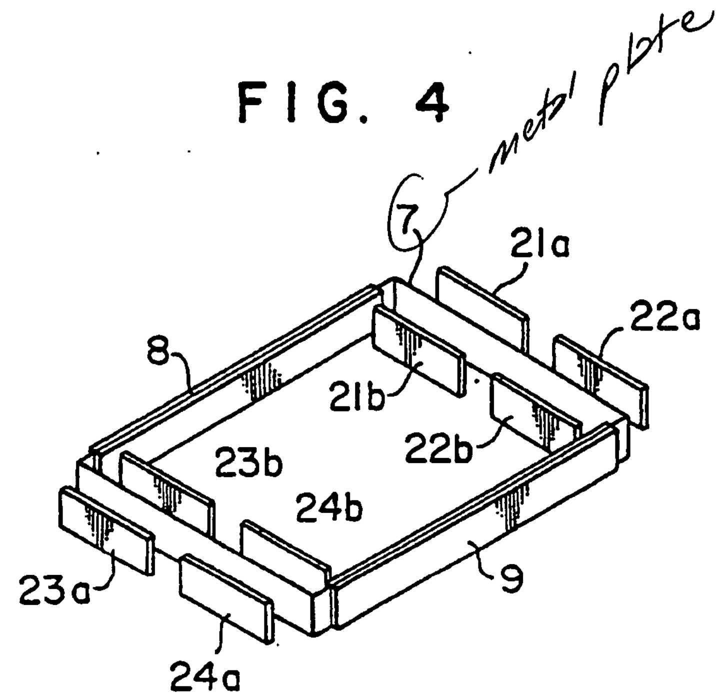

metal plate
7
21a
22a
8
21b
22b
23b
24b
23a
9
24a

FIG. 5

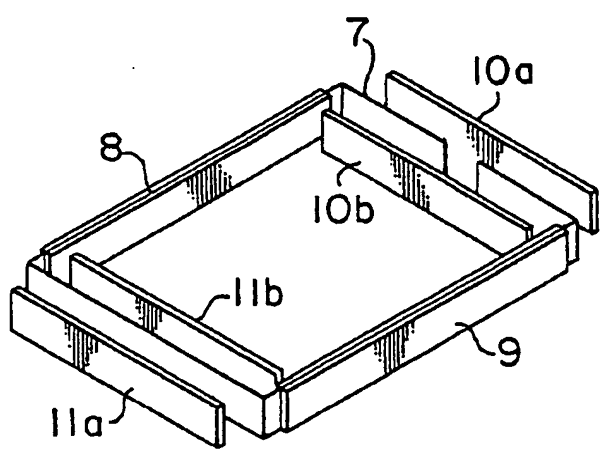

7
10a
8
10b
11b
9
11a

FIG. 6

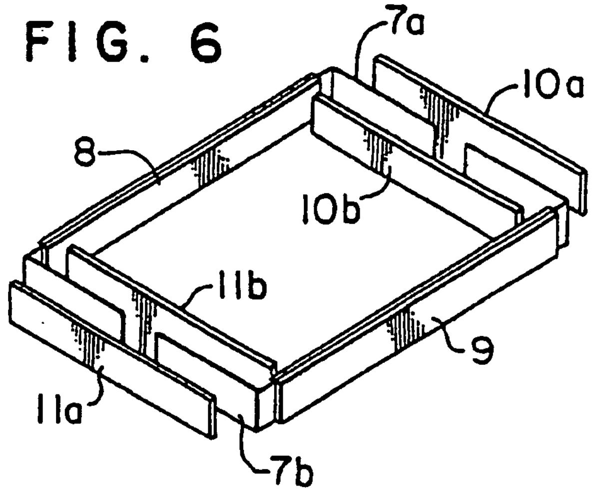


FIG. 7

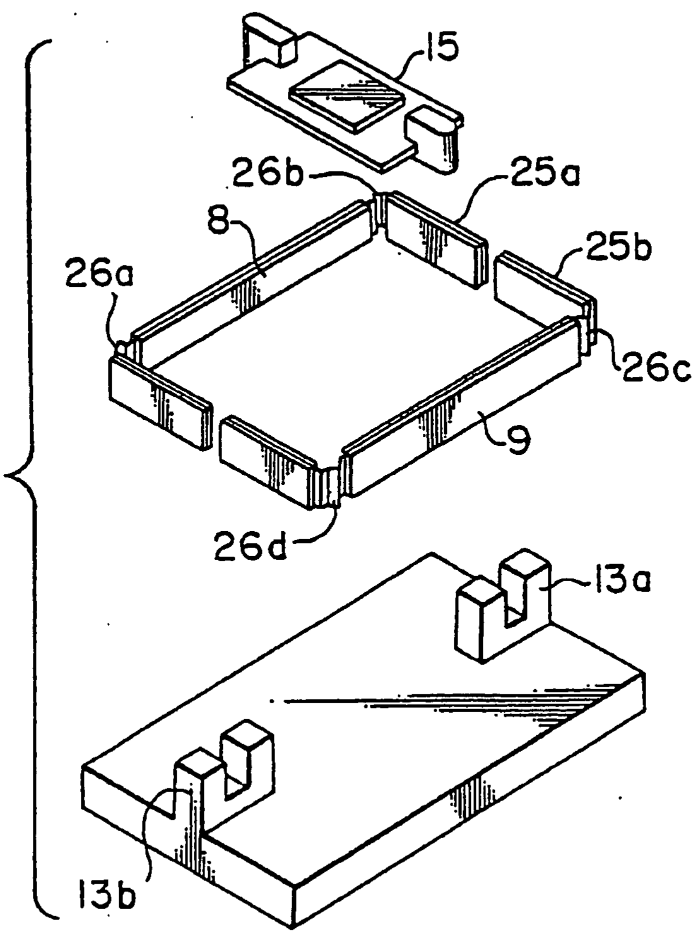


FIG. 8

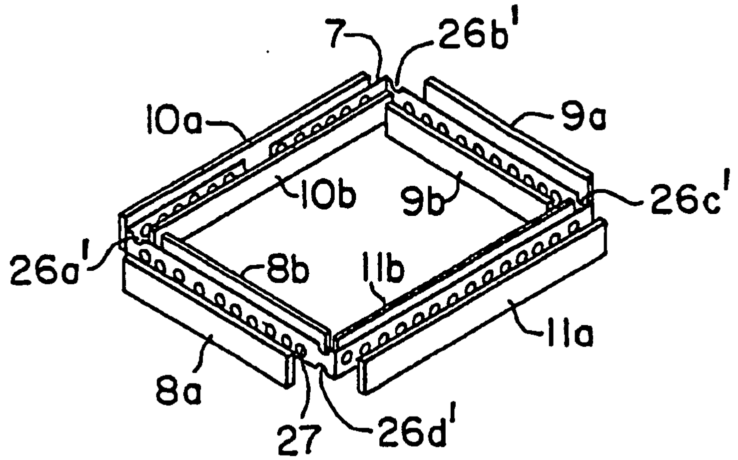

7
26b'
10a
9a
10b
9b
26c'
26a'
8b
11b
11a
8a
27
26d'

FIG. 9A

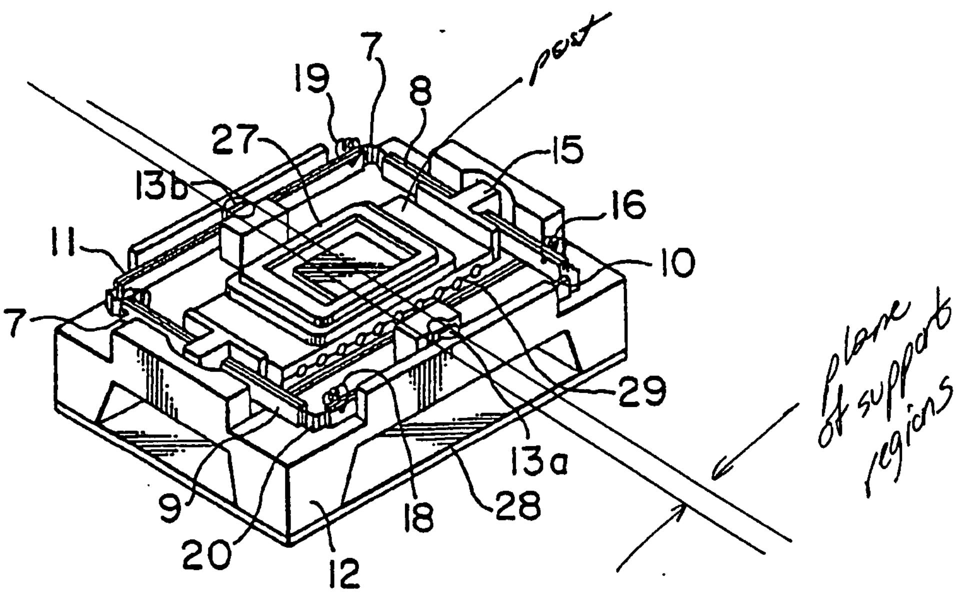

post
7
19
8
27
15
13b
16
11
10
17
29
13a
9
18
28
20
12
plane of support regions

FIG. 9B

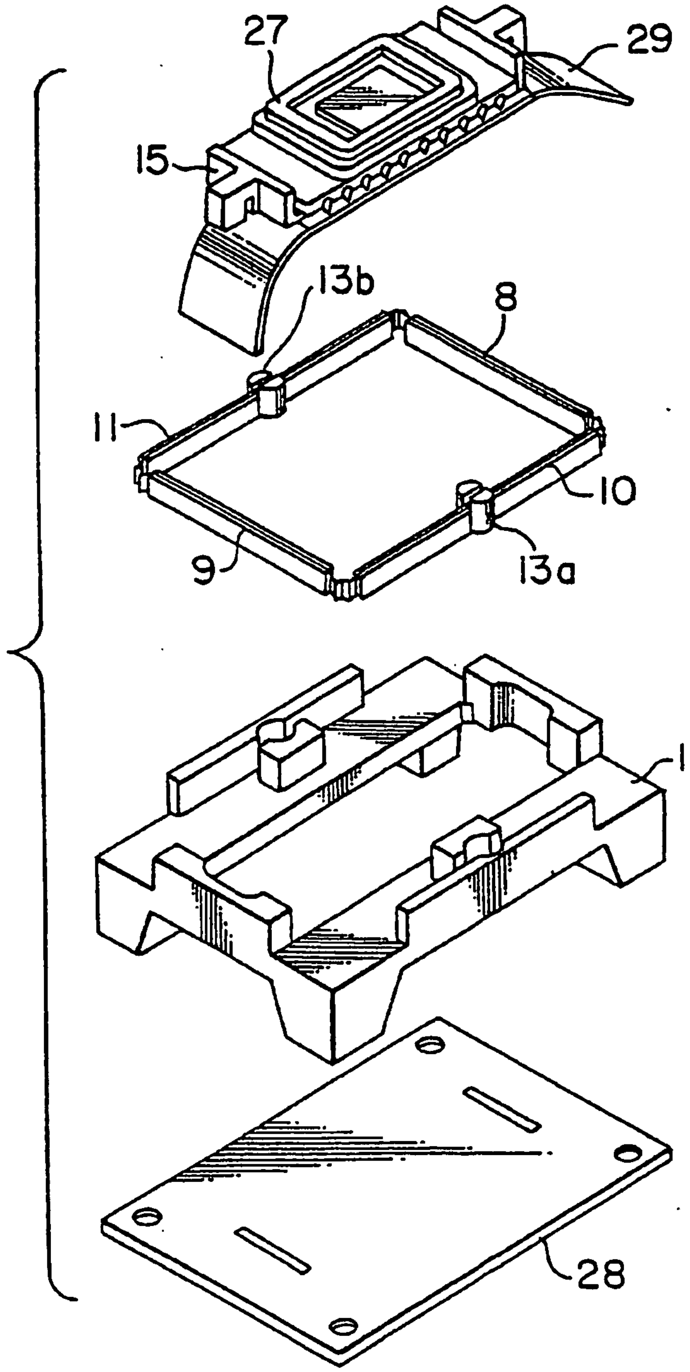
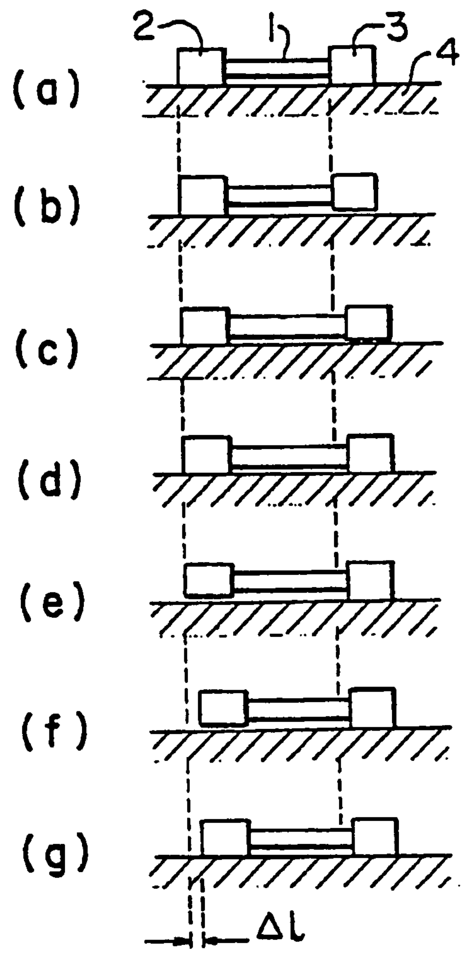


FIG. 10



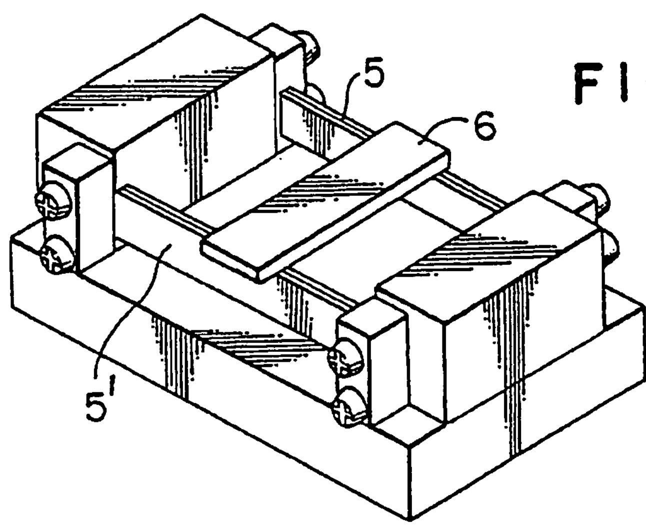


FIG. 11